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TIME RESOLVED MEASUREMENTS OF ARCING IN THE DITE TOKAMAK

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ABSTRACT

Time resolved arcs have been observed in the DITE tokamak using three independent techniques, the observation of the current flowing to a probe, the spectral emission from the probe material and the arc tracks on a rotating disc. The results obtained with the different methods are in good agreement and show that arcing typically occurs in DITE during the first 20ms of the discharge. This short period of arcing is consistent with measurements of the metal impurity flux at the wall which show a similar time dependence.

Observations of the arc current as a function of radial position show that arcing is negligible 3cm beyond the radius of the fixed limiter, in good agreement with the observed arc tracks on projecting surfaces of the torus. The erosion of a probe was estimated from the charge flowing in the arcs and is consistent with previous measurements of the metal impurities deposited at the torus wall.

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INTRODUCTION

There is clear experimental evidence that arcing occurs on surfaces in DITE and other tokamaks.(1,2,3,4,5,) In the DITE (6) tokamak the amount of material removed is sufficient to an order of magnitude to explain the impurity levels observed in the plasma. (1) However, up to now, experiments have been carried out using probes which integrate the effects over one or more discharges and the period during the discharge when arcing actually occurred was unknown.

In order to make time resolved measurements, we have used three techniques. In the first a 38 mm diameter probe consisting of two concentric cylinders is used to measure the current flowing to the inner cylinder as an indication of when arcing is occurring. In the second the optical emission from neutral atoms emitted from the probe is used as a measure of the release of impurity atoms into the plasma. Neither of these techniques by themselves is a completely convincing arc detector but the correlation which has been observed between the two techniques is a strong indication of arcing. Thirdly we have exposed a polished rotating molybdenum disc at the same radial position as the fixed limiter, (minor radius 26cm). The disc is rotated during a discharge so that arcs occurring at different times during the discharge are subsequently detected by examination of the spatial position of arc tracks on the circumference of the disc. Clear evidence of arcing at specific times during the discharge has been observed.

EXPERIMENT

A schematic diagram of the probe and the optical detection system is shown in Fig. 1. The two concentric molybdenum cylinders are insulated from one another and separated by a 1 mm annular gap. The inner electrode can move axially and normally projects 1 cm beyond the outer electrode. They are connected electrically via a 0.1Ω resistor and the outer shield cylinder is normally connected to the torus wall. The current flowing to the inner electrode is monitored by measuring the potential across the resistor. To reduce electrical interference the signal is converted to an optical signal by an electro-optical transducer and is then transmitted to the readout system by a light guide. The visible radiation from the probe is transmitted through a quartz window, light guide and filter to a photomultiplier. An interference filter with a 40 A° bandwidth centered at 5506A°, was chosen to monitor the neutral molybdenum emission. The particular line was chosen as being a strong one in the molybdenum arc spectrum (7) while at the same time being in a position in the DITE plasma spectrum which is free from any strong competing lines. (8) The filament inside the probe assembly is used to align the optical system.

The disc was rotated by a rack and pinion which was actuated via a bellows by a pneumatic cylinder (Fig. 2). Details of this mechanism have been previously described. (9,10) The disc is rotated through 300° in 200ms about a horizontal axis with the plane of the disc parallel to the toroidal magnetic field B_T. The arc current channel is inclined to the probe surface with a current component orthogonal to B_T. (11) The direction of B_T was such that the $\underline{J}\mathrm{x}\underline{B}$ force on the arc current was upwards in the outward facing side of the disc i.e. the side facing away from the centre of the tokamak. In contrast to previous arrangements approximately 120° of the disc was exposed to the plasma at any one time, avoiding the shielding effect of a window. The arc track distributi on fixed probes (11) was an indication that measurable time resolution might be obtained.

RESULTS

The results from the current probe and the photomultiplier are compared in Fig. 3 for a discharge with a plasma current of 150kA. It is seen that current spikes occur predominantly in the early part of the discharge. More detail is shown with a faster time base in Fig. 4. A photomultiplier signal is observed during the first two milliseconds of the discharge without a corresponding current signal and is due to radiation emitted during the ionisation phase.

The pulses have a frequency about 5kHz and are 50-200μs wide with arc currents in the range 2-15 amps. The direction of the current corresponds to electron emission from the inner cylinder. The detailed comparison between the current pulses and the optical signal is shown in Fig. 5. There is a clear correlation between both the time and the amplitude of the two signals. The microwave interferometer signals in the figure show that there is also a correlation of the arc current with small fluctuations in the plasma density. A similar correlation between the high frequency variation in the plasma position and the arc pulses was also observed. This plasma fluctuation usually occurs during the first 10-15ms of the discharge when the plasma is unstable. No correlation was observed between the arcing signals and the plasma x-ray emission which can produce similar but spurious pulses in fibre optic systems.

In previous arcing experiments,(1) using microscopic examination of arc tracks after exposure to discharges, it was observed that the depth of arc tracks decreased as the plasma density increased. With the present measurements a decrease in both the current and the Mo I radiation with increasing density was observed. At a line average density of $3 \times 10^{13} cm^{-3}$, the peak current had decreased by a factor of more than 5 compared to discharges of density $1.5 \times 10^{13} cm^{-3}$. One of the clearest demonstrations of the probe signals being associated with arc tracks was the dependence of the current and emission on the radial position of the probe, shown in Fig. 6. With the fixed limiters at 26cm, no significant signal was observed with the probe 3cm behind the limiters. As the probe was moved in towards the limiter radius the signals increased rapidly. These measurements clearly indicated that the emission was directly associated with the probe. A similar radial dependence of the number of arc tracks on the torus structure has been observed previously.(1,12)

When the probe was withdrawn from the torus, arc tracks were found on its face and sides with a similar track distribution to that observed on previous probes.(1)

The time resolution of the rotating disc was determined by exposing it to the plasma while stationary. Arc tracks were then observed over a 90° sector with the majority of the arcs originating at the circumference of the disc. In all cases the arc tracks were parallel to the vertical minor diameter of the torus and therefore only arcs originating near this diameter produced tracks along a radius of the disc. When non-radial tracks on the discs are ignored a resolution better than 10ms is obtained, equivalent to having a window smaller than a 15° sector of the disc.

A typical example of the arcs observed on the rotating disc after exposure to the plasma for three discharges is shown in Figure 7. Many small arc tracks with an average length of 0.2mm, grouped in two distinct regions, are observed around the edge of the disc on the side facing the torus centre. Two of the three discharges to which the disc was exposed were disruptive, resulting in an abnormally short discharge. Arc tracks were observed on the disc at a time corresponding to this disruptive period which also produced signals from the concentric arc detection probe. A histogram of the number of arc tracks as a function of time is shown in Figure 8(a) and the probe current histogram obtained simultaneously for the same three discharges in Figure 8(b). During the first 20ms there is less than 1 arc per ms. However, this is a lower limit since arcs < 0.15mm long and non radial tracks formed during this time are not plotted. Taking all arcs into consideration gives an average arcing rate durin the first 20ms of 4 arcs per ms which is in good agreement with the value of 2 arcs per ms over the same period obtained using the concentric probe.

The period of arcing as determined by the rotating disc and probe signals for a single non disruptive charge is shown in Figure 9. This is typical of non-disruptive discharges in DITE for gas currents of 150kA where arcing is only observed in the initial phase of the discharge near peak current.

DISCUSSION

The good correlation between the current flowing in the probe and the molybdenum radiation is strong evidence that both these signals indicate that arcing is taking place. Confirmation that arcing occurred is obtained from the visual observation of the arc tracks on the current probe and the agreement between the probe signals and the time resolved arc tracks on the rotating disc. Both the optical and the current signals could thus be used by themselves for arc diagnosis in arcing studies in tokamaks, the optical method being particularly useful where limited access to torus components may make current measurements impossible.

Estimates of the erosion by arcing based on the frequency and dimensions of arc tracks have been previously reported.(1) It was shown that the amount of metal produced was consistent with the observed density of metal deposited on the internal surfaces of DITE. For high density gettered discharges a total metal deposition of 4×10^{12} atoms cm^{-2} per discharge was measured, of which 10^{12} atoms cm^{-2} were molybdenum. The emission rate of metal from an arc has been shown to depend primarily on the charge flowing(13) and for molybdenum it is 5×10^{-4} gm C^{-1}. The average charge flowing to the concentric probe is 10^{-2}C which produces 4×10^{15} atoms per discharge. If this metal is distributed uniformly over the torus an average surface density of 3×10^{10} atoms cm^{-2} is obtained. The probe's active area is however less than 0.1% of the surface area subject to arcing on the fixed limiters and this value is therefore consistent with the observed deposition.

For the discharges investigated so far, arcs occur during a short period associated with the instabilities which are always present at the start of the discharge in DITE. Metal impurities will therefore be injected into the outer region of the plasma during this period, which is typically 5-20ms from the start of the discharge. There is substantial evidence that the edge of the plasma is unstable with a short confinement time, ∿ 1ms or less. Most of the metal injected into the plasma during the arcing period will therefore be removed in a few milliseconds, resulting in a pulse of metal early in the discharge. This is consistent with previously reported measurements(10) of metal collected on a rotating carbon disc which show a pulse in the metal flux at 27cm minor radius in the first 50ms of a high density gettered discharge. The present results were obtained for similar discharges and this agreement is additional evidence that arcing is responsible for the production of metal impurities in DITE. The short period of arcing however shows that measurements of impurities in the plasma integrated over the whole discharge can over estimate the metal impurity concentration for most of the discharge.

CONCLUSIONS

Convincing evidence has been presented that arcing in the DITE tokamak can be detected by observing the current and neutral emission from the concentric probe. These results were confirmed by the direct observation of arc tracks on a rotating disc.

The probe signals show a strong radial dependence and arcing is negligible 3cm beyond the radius of the fixed limiter. The time resolved results show that arcs occur predominantly during the early part of the discharge. The three methods used are in good agreement and the time dependence of arcing is also consistent with previous measurements of the impurity concentration in the plasma boundary, which showed that the impurities entered during the rising current phase.(9,10)

Using data from the literature on the number of atoms released in an arc per coulomb of charge, it is possible to make an estimate of the rate of injection of impurities into the discharge from the arcing probe. If it is assumed that the number of impurities is proportional to the area exposed at a given radius then the number of impurities from the limiter are sufficient to explain the surface density of metal impurities on the wall of the vacuum vessel.

The use of either the current probe or the optical emission method is a simple but effective tool for arc detection, and has been shown to be suitable for the investigation of arcing in the DITE tokamak.

ACKNOWLEDGEMENTS

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REFERENCES

1. McCracken G M and Goodall D H J. Nuclear Fusion 18, 1978, 537.
2. Staib P and Staudenmaier G. J Nuclear Materials 63, 1976, 37.
3. Cohen S A, Dylla H F, Rossnagel S M, Picraux S T, Borders J A and Magee C W. J Nuclear Materials 76/77, 1978, 459.
4. Colchin R J, Bush C E, Edmunds P E, England A C, Hill K W et al. J Nuclear Materials 76/77, 1978, 405.
5. Staib P and Staudenmaier G. J Nuclear Materials 76, 1978, 78.
6. Paul J W M et al. Proc of 6th Conference on Plasma Physics and Controlled Nuclear Fusion Research, Vol II, Berchtesgaden, 1976, 269.
7. Meggers W F, Corliss C H and Schribner B F. Tables of Spectral Line Intensities. NBS Monograph 32 Part I, Washington, 1961, page 145.
8. Fielding S J. Private communication 1978.
9. Dearnaley G, McCracken G M, Turner J F and Vince J. Nuclear Inst. and Methods 149, 1978, 253.
10. McCracken G M, Dearnaley G, Gill R D, Hugill J, Paul J W M, Powell B A, Stott P E, Turner J F and Vince J. J Nuclear Materials 76/77, 1978, 431.
11. Goodall D H J and McCracken G M. Culham Laboratory Report CLM-R167, 1977
12. Goodall D H J, Conlon T W, Sofield C and McCracken G M. J Nuclear Materials 76/77, 1978, 492.
13. Kimblin C W. J Applied Physics 44 1973, 3074.

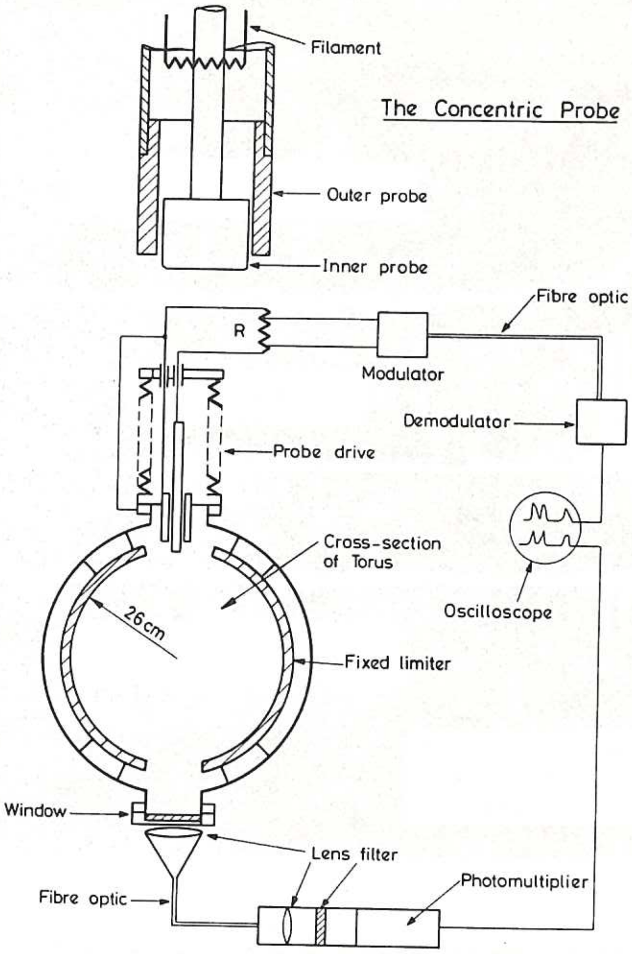

Fig.1 A schematic diagram of the arc detection system.

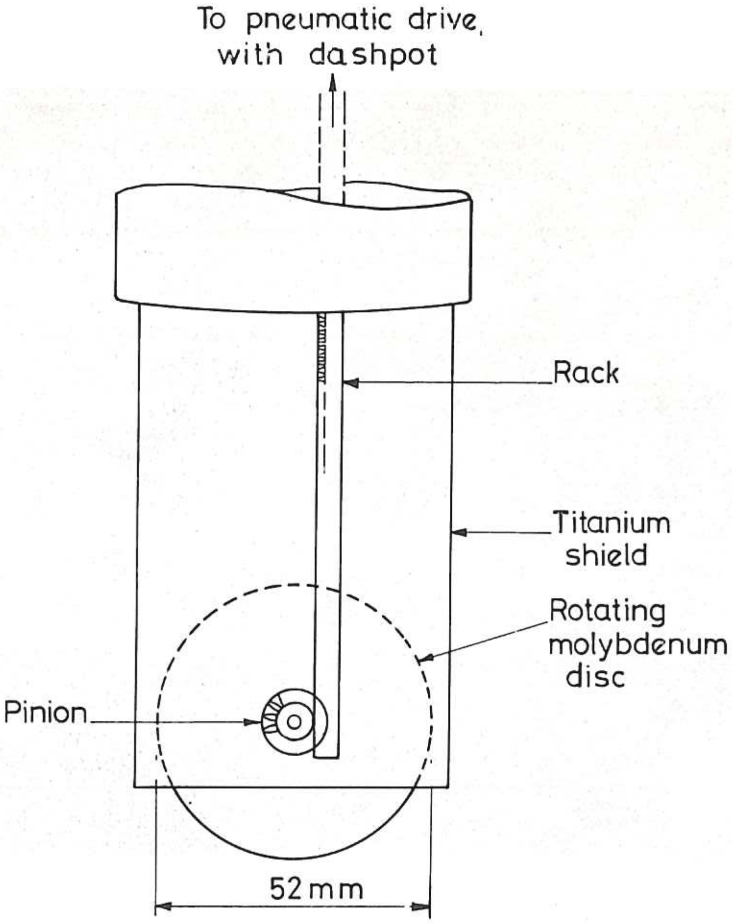

Fig.2 The rotating disc and drive mechanism used for the direct observation of time resolved arc tracks.

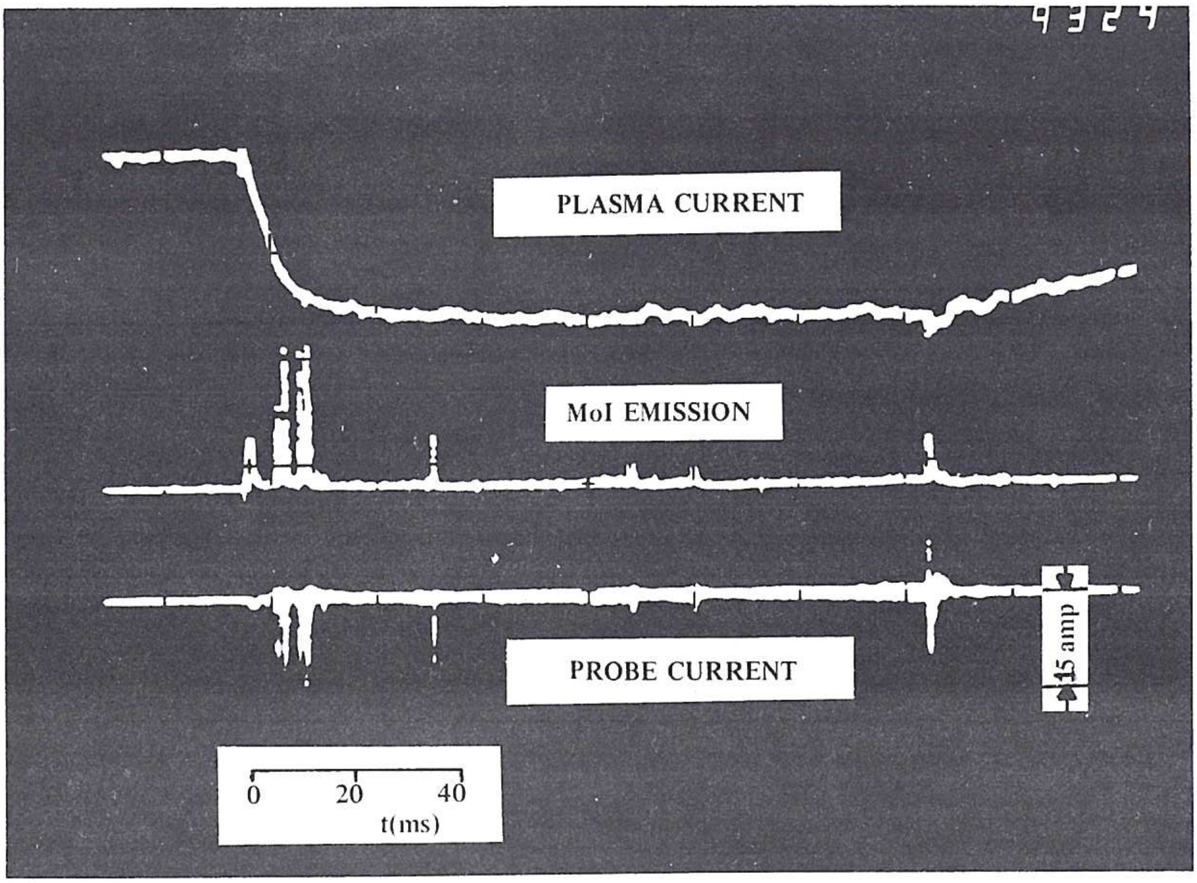

Fig.3 The typical arcing period for a gettered discharge.

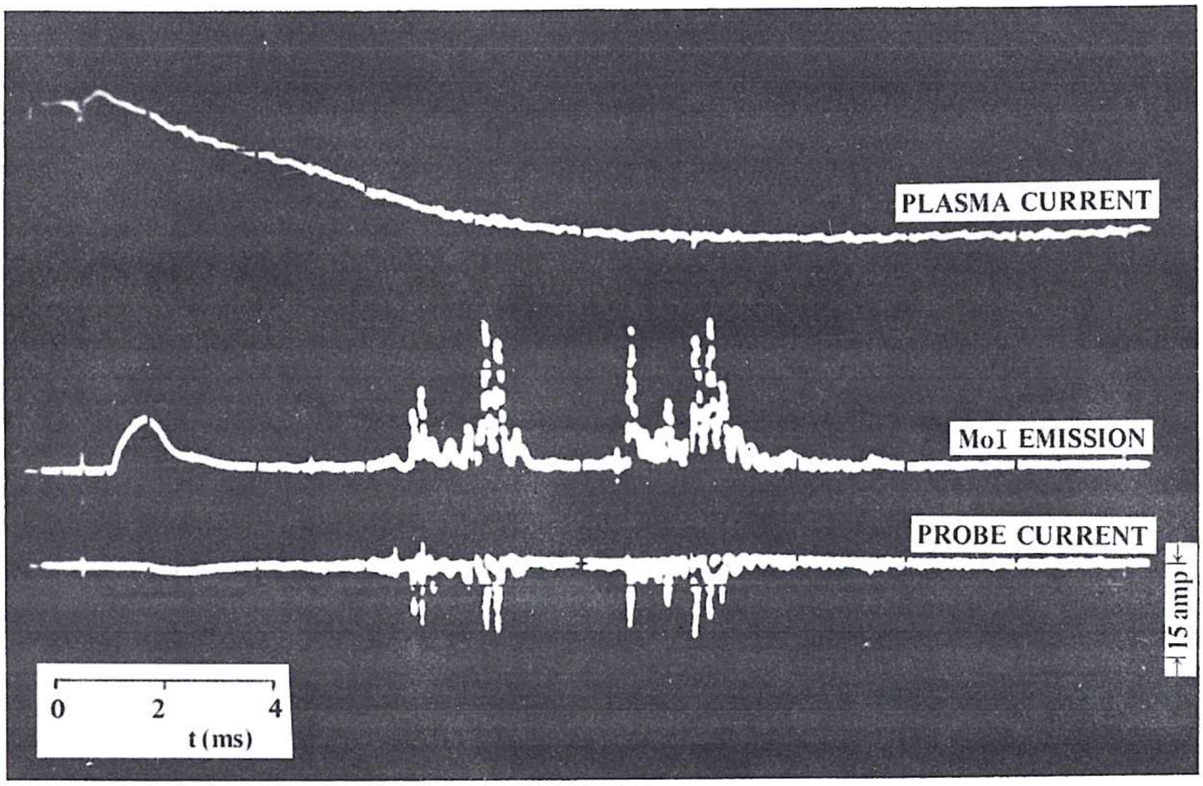

Fig.4 The initial arcing period for shot 9329.

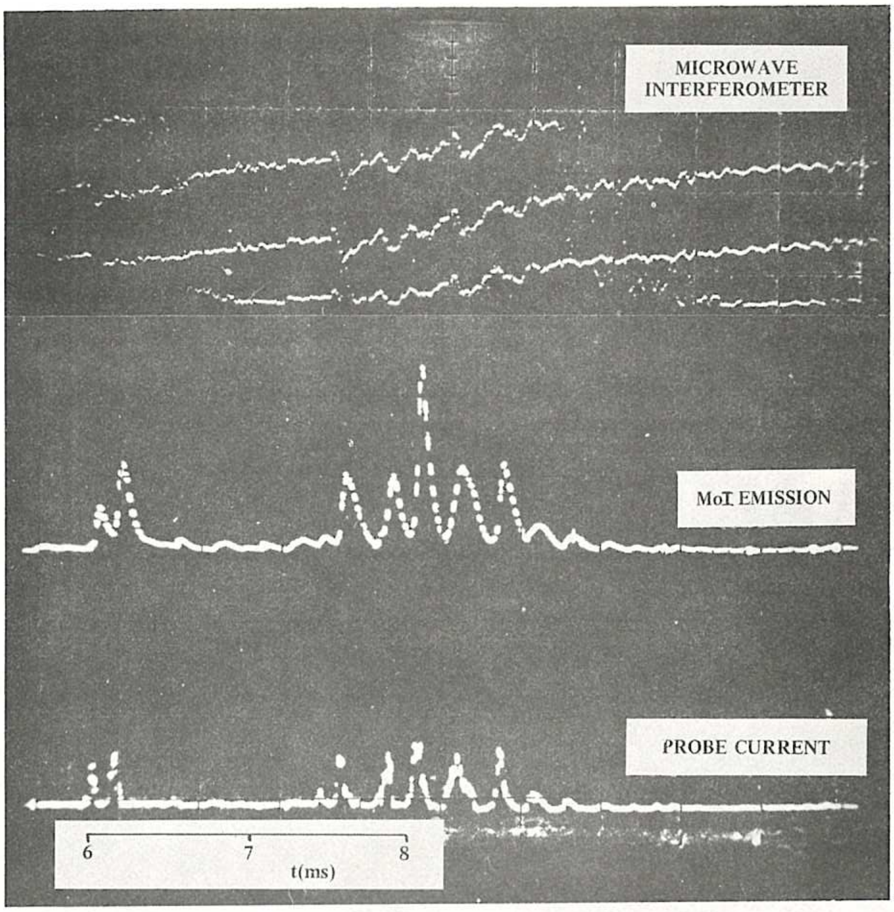

Fig.5 The correlation between probe current, MoI emission and the microwave interferometer fluctuations.

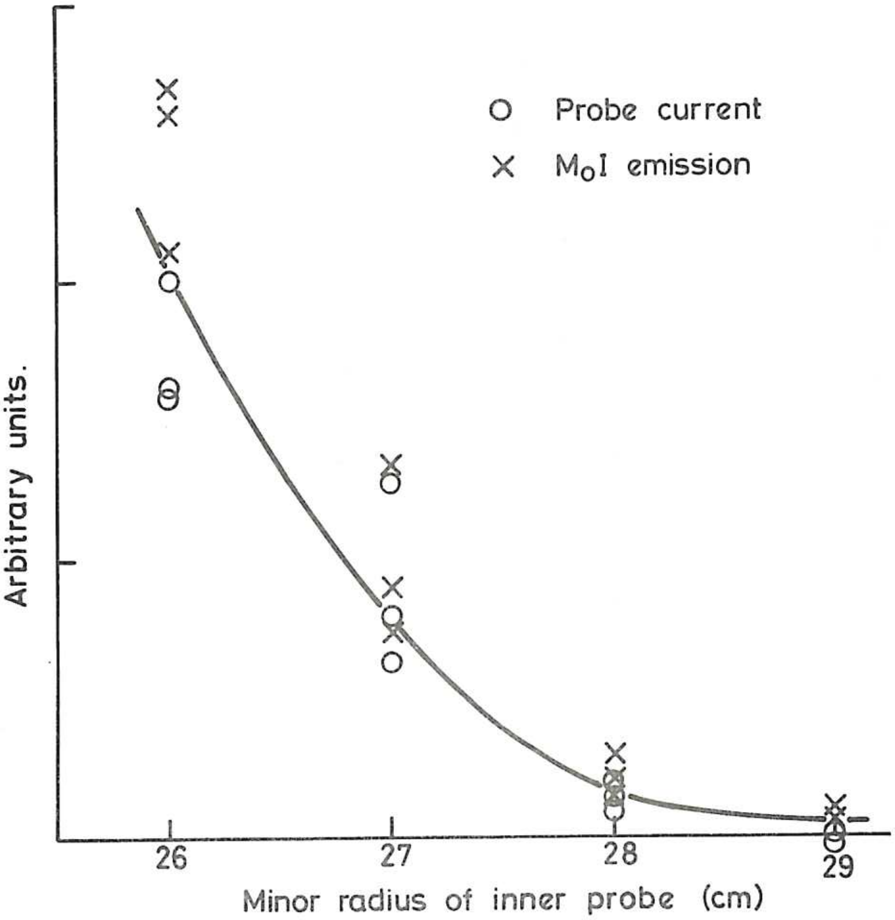

Fig.6 Arcing intensity as a function of the minor radial position of the probe.

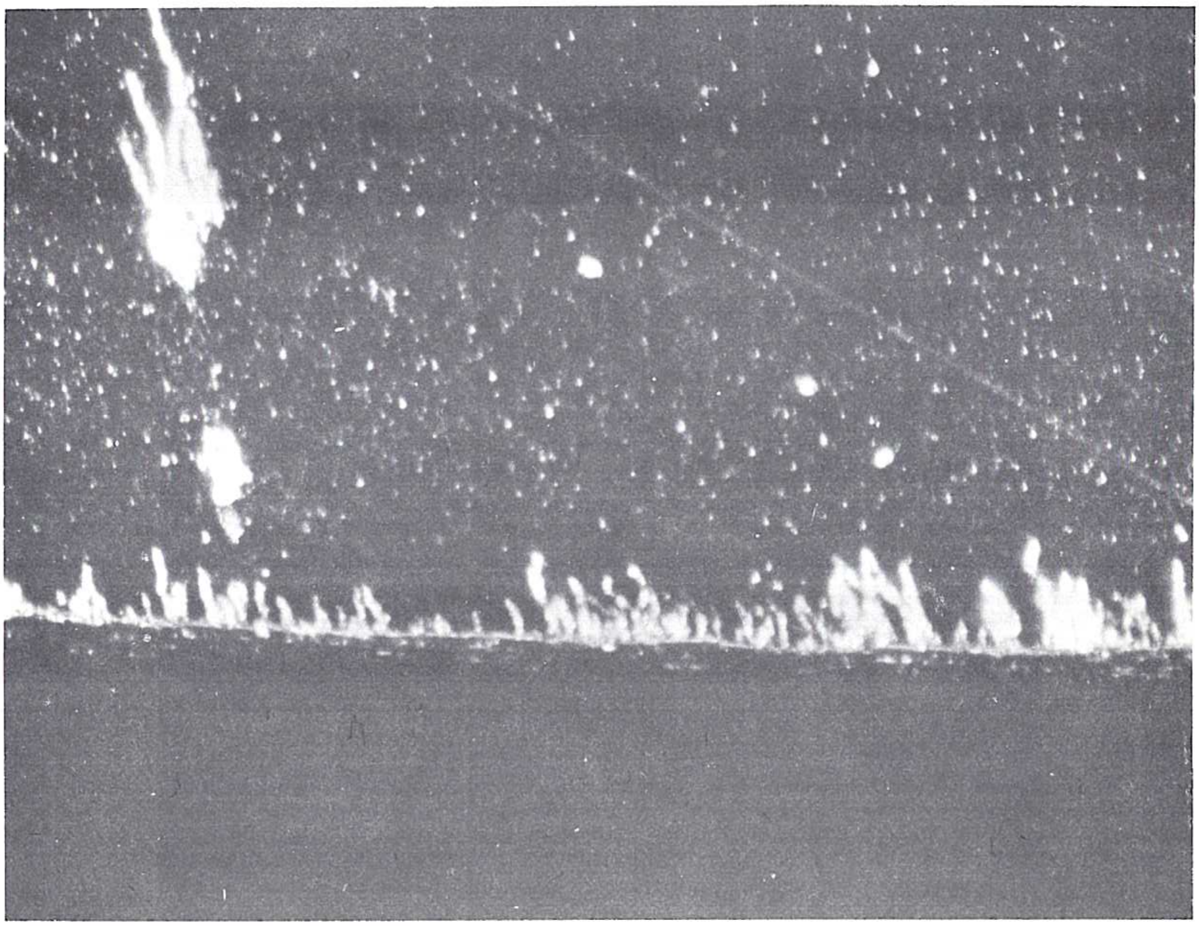

Fig.7 Part of the circumference of the rotating disc showing arc tracks.

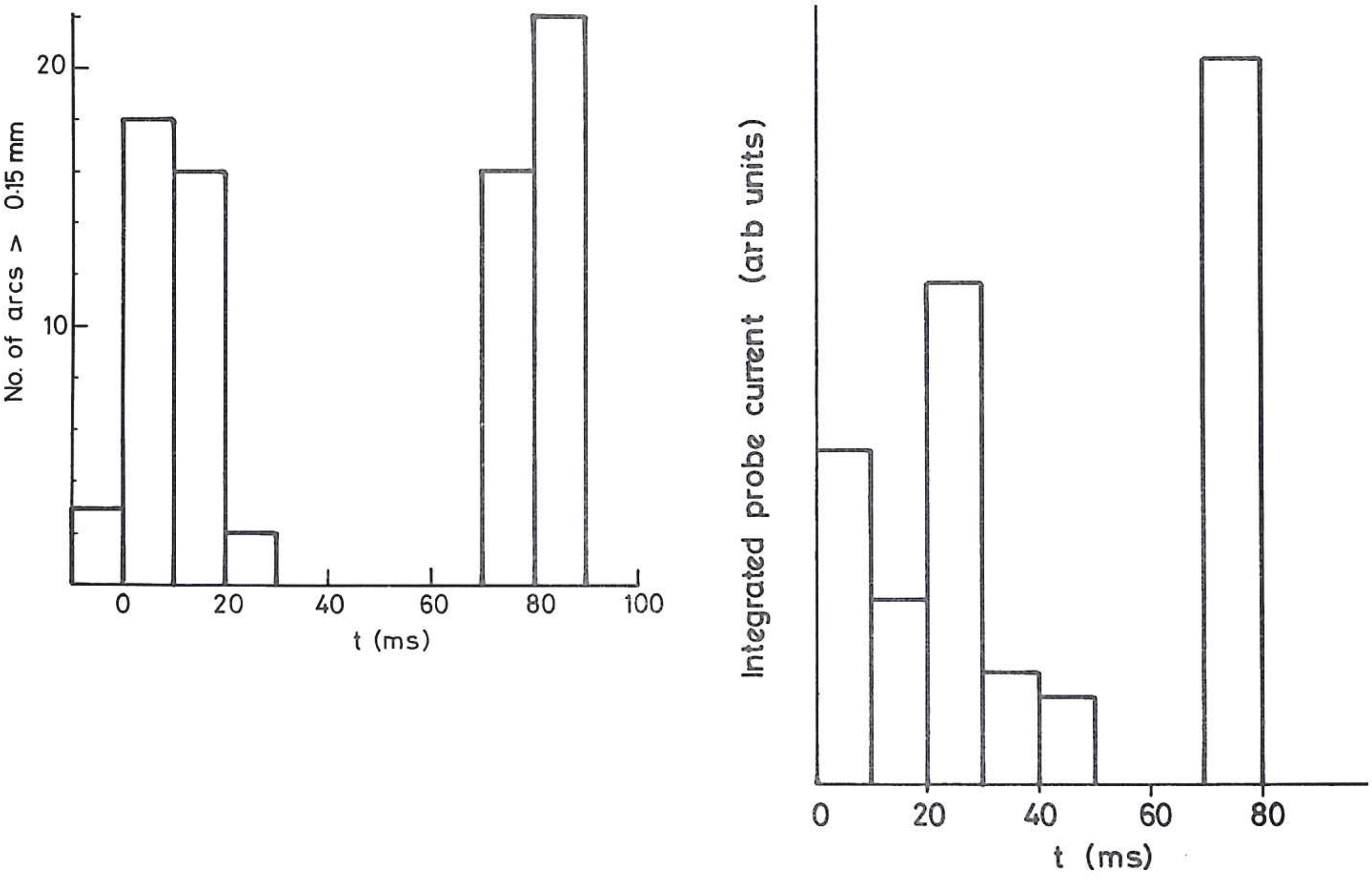

Fig.8 A comparison of the distribution of arcs for three discharges using the disc and the concentric probe, (a) arc track distribution from the disc, (b) current distribution from the probe.

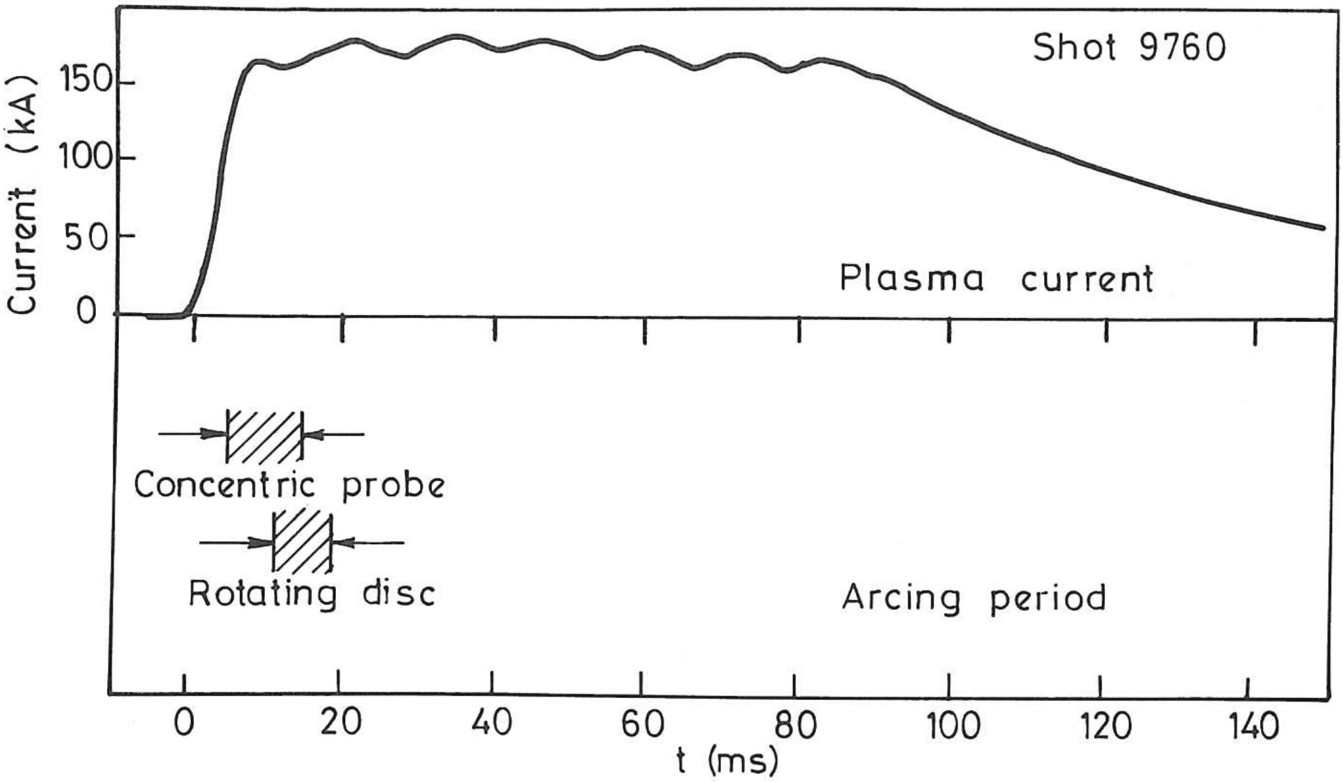

Fig.9 The arcing period for a single discharge as determined by the rotating disc and the concentric probe.